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AIRFLOW DETERMINATION FOR RADIATION EMANATION INVESTIGATIONS OF A LARGE WORKED OUT AREA OF A URANIUM MINE

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AIRFLOW DETERMINATION FOR RADIATION EMANATION INVESTIGATIONS OF A LARGE WORKED OUT AREA OF A URANIUM MINE

by

S. Hardcastle* and J. Bigu**

ABSTRACT

The determination of airflow parameters, including quantity flow, average residence time and total clearance time, is crucial in determining radon emanation rates in order to model or predict underground radiation levels.

Documented are two tracer gas investigations of a large area of a uranium mine comprising 19 stopes in two reefs and associated drivages. Sulphur hexafluoride, SF_6, was the tracer gas employed. Measurement and analysis of SF_6 were performed by a grab-sampling and later laboratory-based gas chromatography method. Pulse and continuous tracer gas injection methods were used and standard anemometry was used concurrently with both.

For normal working conditions, the tracer gas analysis gave an average residence time of 24 minutes and a total clearance time of 300 minutes. The latter was greatly influenced by the 9 to 15% air being recycled in the ventilation system. The injections also highlighted disproportionate dilution of the airstreams in the area being evaluated.

Radioactivity concentrations and Working Level ratios of radon gas and radon and thoron progenies, derived from radiation measurements taken during the investigation, show the area to be reasonably well ventilated.

Key words: Ventilation; Tracer gas; Radiation.

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DÉTERMINATION DE LA VITESSE D'ÉCOULEMENT DE L'AIR DANS LE BUT D'ÉTUDIER L'ÉMANATION DE RAYONNEMENTS DANS UNE GRANDE SECTION ÉPUISÉE D'UNE MINE D'URANIUM

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RÉSUMÉ

Quand il s'agit d'évaluer les taux d'émanation de radon pour modeler ou prédire les niveaux de radiation souterraine, la détermination des paramètres de l'écoulement de l'air, y compris le débit, le temps de séjour moyen et l'intervalle de dégagement, est d'une grande importance.

Les auteurs présentent un compte rendu détaillé de deux études, effectuées avec du gaz trace, d'une grande section d'une mine d'uranium. La mine comprenait 19 chantiers d'abattage et des galeries attenantes répartis sur deux filons. Pour les besoins de l'étude, on a utilisé de l'hexafluorure de soufre (SF_6). La mesure et l'analyse du SF_6 ont été effectuées par échantillonnage au hasard et plus tard, en laboratoire par la méthode de chromatographie en phase gazeuse. On a procédé par les méthodes d'impulsions et d'injections continues de gaz trace en utilisant, dans chaque cas, un anémomètre ordinaire.

Dans des conditions normales de travail, l'analyse par injection de gaz trace a révélé que le temps de séjour moyen de l'air était de 24 minutes et le temps de dégagement total, de 300 minutes. Ce dernier a été considérablement influencé par la quantité d'air (de 9 à 15 %) qui était recyclé dans le circuit d'aération. Les injections de gaz ont également attiré l'attention sur la dilution disproportionnée de l'air en circulation dans la section contrôlée.

Mots clé : Ventilation; Gaz trace; Rayonnement.

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La mesure des rayonnements effectuée pendant l'étude a permis de déterminer les concentrations de radioactivité et le niveau acceptable des émanations de gaz radon et des descendants de radon et de thoron dans le milieu de travail et de démontrer que la ventilation de la section est adéquate.

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INTRODUCTION

For modelling and predicting radiation levels in underground uranium mines, a prerequisite is the radon emanation rate or radon flux of the mine walls. An area of Rio Algom's Stanleigh Mine was preselected for a radiation study to determine the strata emanation from a large worked-out area. To aid the radiation studies the airflow was also investigated using tracer gas techniques. The area under investigation comprised stopes in both reefs.

The ventilation study was in two parts:

i) prior to the emanation study, evaluation of the airflow though the region using a continuous injection technique; and

ii) a pulse injection during the study.

Only two injections could be performed because of time constraints in both sampling and analysis. Radiation studies, concurrently carried out with present ventilation studies, are reported elsewhere (1).

DESCRIPTION OF TEST LOCATION AND BASIC AIRFLOW REGIME

A simplified diagram of the area is shown in Figure 1. The original area delimited for investigation contained 8 stopes (#37640 to #39647) in the main reef and 11 stopes (#396001 to #396201 and #416011 to #416091) in the lower reef. The stopes in the main reef are ventilated directly from a fresh air raise via #37025 drivage, after which the exhaust from the stopes combines along with the exhaust from a mechanized haulage level, #39021. The airstream then splits and takes two different routes to and through the lower reef before reaching the exhaust shaft. Air from other parts of the mine also converged at this exhaust shaft.

Fresh air drivage #37025 was ideal for the introduction of sulphur hexafluoride, SF_6, tracer gas. The other airflows at the exhaust shaft,

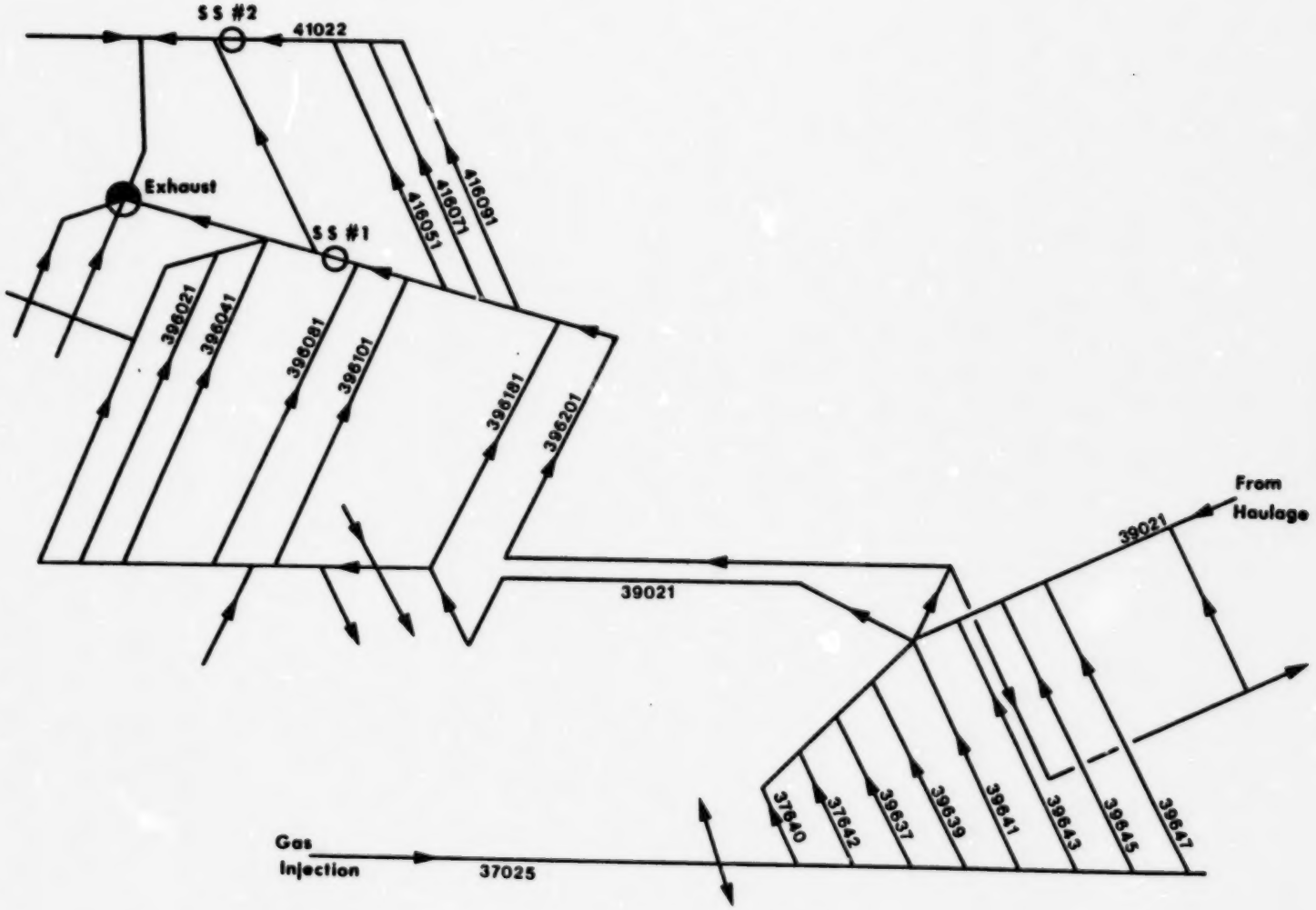

Fig. 1 - Simplified layout of stopes and drivages of test location including air direction.

however, necessitated splitting the final sampling station and locating upwind of the shaft. This halved the sampling density possible for the initial investigation and also removed four of the lower reef stopes from the area to be evaluated.

PRE-STUDY INVESTIGATION OF THE AIRFLOW

The nominal flow through the area under investigation was 56.7 m^3/s (120 000 cfm) of fresh air plus 47.2 m^3/s (100 000 cfm) from haulage for a maximum throughput of 103.9 m^3/s.

A continuous SF_6 injection release was used as it easily provides a tracer for the airflow through the system. The injection release rate was optimized for operational considerations. These considerations included gas availability, duration of gas release, control of release and maximizing the final mixed concentration of SF_6 in air to be measured. Ultimately a release rate of 60 mL/min of pure SF_6 was selected to give a final concentration in the order of 10 ppb.

The gas chromatograph optimized for SF_6 was manufactured by S-cubed, California. It was calibrated in the 50 to 2 ppb range using standards and controlled splits of standards (2). Calibration data are given in Appendix 1.

The gas was released from a #2 gas bottle, as supplied by Canadian Liquid Air, with a restricting length of 0.01" diameter capillary tubing. The release location is shown in Figure 1. On installation underground the flow rate of gas was 56.49 $\pm$ 1.83 mL/min. This was measured using a Buck calibrator, a bubble tube with electronic timing. The injection was allowed to last approximately 22 h. Prior to stopping the gas, the flow was measured at 55.63 $\pm$ 2.16 mL/min. The flow was assumed to have remained constant over this period with an average flow of 56.34 $\pm$ 1.9 mL/min.

The air flowing through the stopes was sampled both prior to the end of

the injection of SF_6 and after the injection. Thus both a steady state concentration of tracer gas and its decay were monitored. The sampling survey stations (SS) are shown in Figure 1. Samples were taken at 15 minute intervals using Gilian* constant flow pumps and Tedlar** sampling bags with in/out sampling ports. The pumps delivered approximately 1 L/min and were allowed to run for 30 seconds into a 1 litre bag.

At each survey station 23 grab-samples were taken over 5.5 hours. Additional samples were taken;

i) in fresh air and prior to the release of the gas to quantify any background; and

ii) downwind of the release to determine the dilution in the main reef prior to the introduction of air from the haulage level.

The gas chromatograph analysis results from the grab-samples at the two locations are presented graphically in Figures 2 and 3. The steady state concentrations differ at the two survey locations, with the concentration at #2 (rescue station) being the higher. The SF_6 concentrations were :

Station #1 13.10 ppb

Station #2 14.39 ppb

These values have been corrected for a background of 0.63 ppb.

The airflow may be obtained using Equation 1:

$$Q = \frac{v\ 10^9}{C} \qquad \text{Eq 1}$$

where, Q is the airflow, m^3/s,

v is the SF_6 flowrate, m^3/s, and

C is the SF_6 concentration, ppb

The SF_6 volume flow rate was 56.34 mL/min or 0.94×10^{-6} m^3/s.

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*Trade name. **Material trade name of DuPont Corporation.

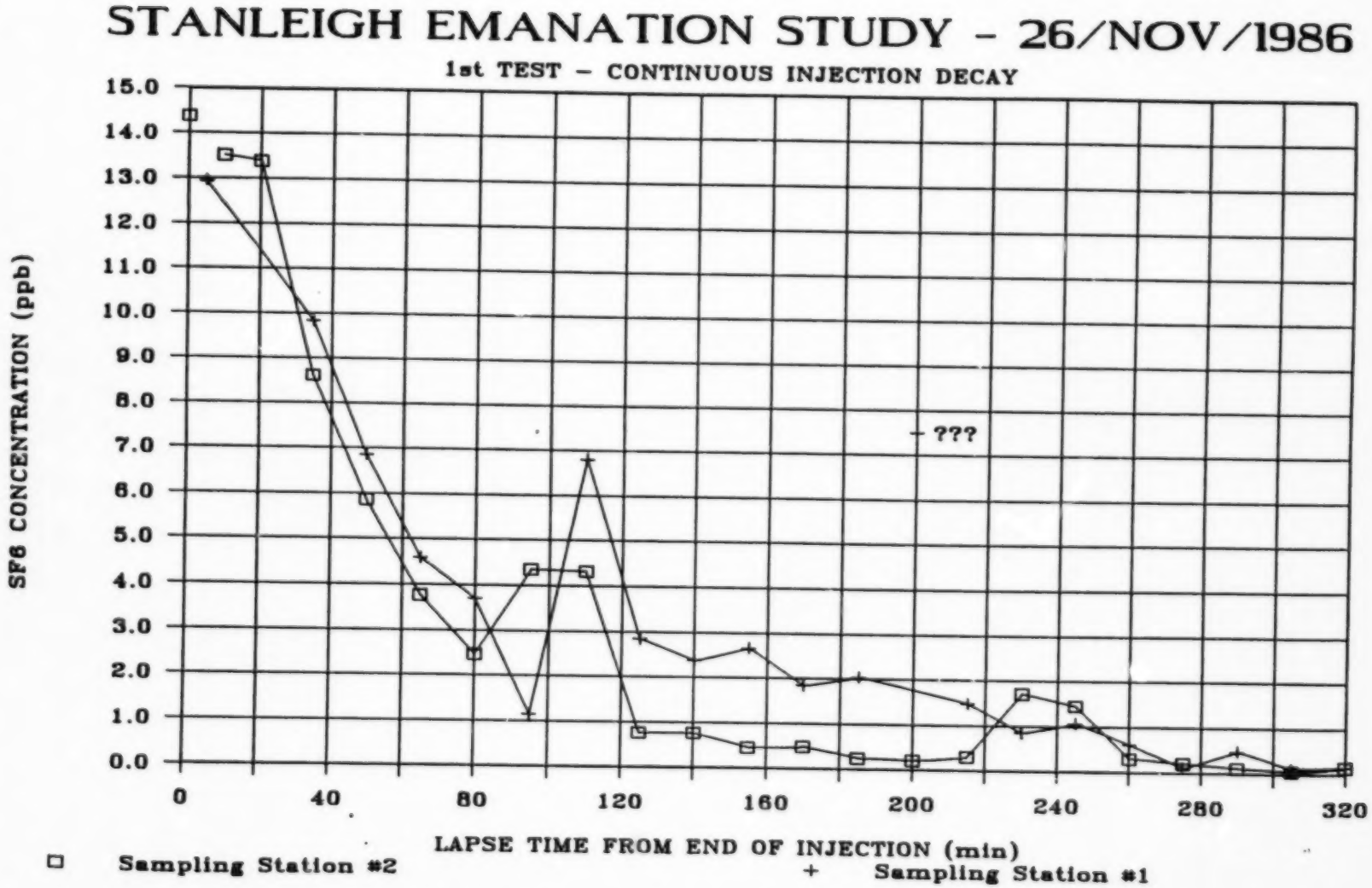

Fig. 2 - Basic analysis of continuous SF_6 injection decay at the two sampling stations.

Thus the airflow was:

Station #1 $0.94 \times 10^{-6} / 13.10 \times 10^{-9} = 71.76$ m^3/s (152 000 cfm).

Station #2 $0.94 \times 10^{-6} / 14.39 \times 10^{-9} = 65.32$ m^3/s (138 000 cfm).

The airflow samples downwind of the release point provided erroneous data and cannot be used to determine the airflow in the upper reef stopes. Standard anemometry methods gave 51.94 m^3/s (110 000 cfm) at the injection point.

The flow at the release point and overall through the system are significantly lower than the expected values, namely, ~55 m^3/s at the intake and ~100 m^3/s through the system. This was due to the exhaust shaft containing road bed material that had been dropped for roadway maintenance the following day. This material partially blocked the shaft airpath, which in turn increased the resistance of the shaft and redirected some of the normal airflow.

The difference in values between Station #1 and Station #2 shows that the air reaching the two stations is disproportionately diluted.

Figure 2 shows the decay of the SF_6 concentration at the sampling stations, and Figure 3 shows the curves after being normalized to percentages of their steady state concentration. In both decay curves there are peaks that are uncharacteristic of a normal decay. These peaks would tend to indicate that the air is being recycled at some point in the system. At Station #2 there are two peaks which decay by approximately 31% each time. At Station #1 the first peak is less than the steady state concentration but a second possible peak (designated ??? in Figure 2) is greater than the first. This is impossible for the type of release used and the ventilation system, therefore this peak is erroneous and has been omitted.

For both stations the peaks have a delay time of 100 to 115 minutes for the first peak and also between peaks for Station #2. This again suggests air

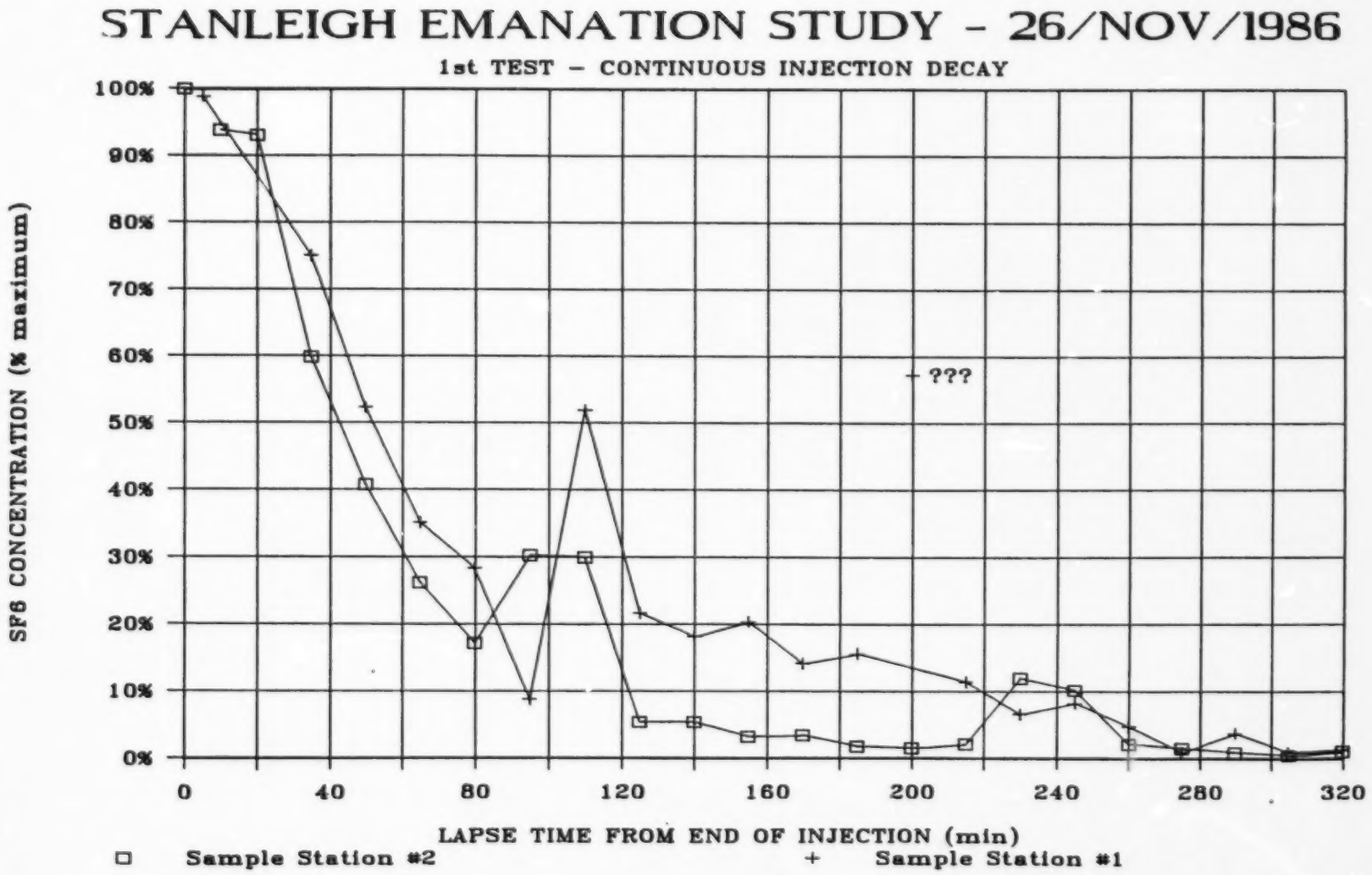

Fig. 3 - Analysis of continuous SF_6 injection decay normalized to percentage of steady state concentration.

is being recycled in the system.

The curves of Figure 3 also supply the average residence time of the system. This corresponds to the time for the concentration to decay to 50% of the steady state concentration. For the flow to Station #2 the average residence time was 43 minutes, and for Station #1 the time was 52 minutes. At both stations the whole decay including the recycle peaks takes 300 minutes.

For the second injection when radiation measurements were made, a pulse injection was to be used. A quick differentiation of this decay curve using the 15 minute sample values up to the first peak provides approximate information of an equivalent pulse injection. The equivalent pulse would produce a maximum of 4.77 ppb and an under-curve area of 11000 ppb·s. Such an under curve area could have been produced directly by an instant release of 750 mL of SF_6. For the pulse injection a peak of 20 ppb was desired, requiring 3000 ml to be released.

PULSE INJECTION ANALYSIS

A greater density of samples is needed for defining the resultant concentration curve from a pulse injection, thus only Station #1 was used for sampling.

The gas chromatograph calibration was rechecked for the 30 to 1 ppb range. During analysis the carrier gas for the chromatograph and also the separation column/coil needed changing. This resulted in various calibrations being used in the analysis. All results from the calibration are included in Appendix 1.

The gas was to be released by bursting a balloon of SF_6. Care was taken in filling the balloon in an airstream that would not pass the sampling station. The balloon was filled from a lecture bottle with flow regulation

through capillary tubing. An in-line Buck calibrator was used to monitor the flow rate. The balloon was filled at 267.3 $\pm$ 1.13 mL/min for 12.14 minutes to provide a release volume of 3.246×10^{-3} m^3 SF_6.

Forty grab-samples were taken regularly over 280 minutes with Gilian pumps and 1 litre Tedlar sampling bags. The results of the laboratory analysis are presented graphically in Figures 4 to 6. The pulse injection produces a primary peak which lasts 100 minutes, followed by a secondary peak again at 110 to 120 minute elapsed time. This agrees with the recycling of air evident in the continuous injection results.

The airflow is determined using Equation 2:

$$Q = \frac{v.10^9}{C_\tau} \qquad \text{Eq 2}$$

where, v is the volume of gas released, m^3, and

C_τ is the area under the time concentration curve, ppb·s.

The area under the curve in Figure 4 up to the recycle peak is 34000 ppb·s and 3.246×10^{-3} m^3 SF_6 was released, thus the air flow was 95.5 m^3/s or 202 000 cfm. The recycled peak and decay contain another 3000 ppb·s, which represents 9% being recycled.

Figure 5 shows the cumulative SF_6 concentration curve by pulse injection. This curve is equivalent to that which would be exhibited for the build-up of tracer by continuous injection to steady state. The curve has two distinct parts, firstly, the rapid rise and levelling out to a quasi-steady state, and secondly, the increase resulting from air being recycled.

In Figure 6 the initial part of the curve has been converted into a cumulative percentage curve, which facilitates finding the average residence time at 50% of the total.

The average residence time for pulse injection was 24 minutes. This value is less than that for the previous continuous injection, namely 43 to 52

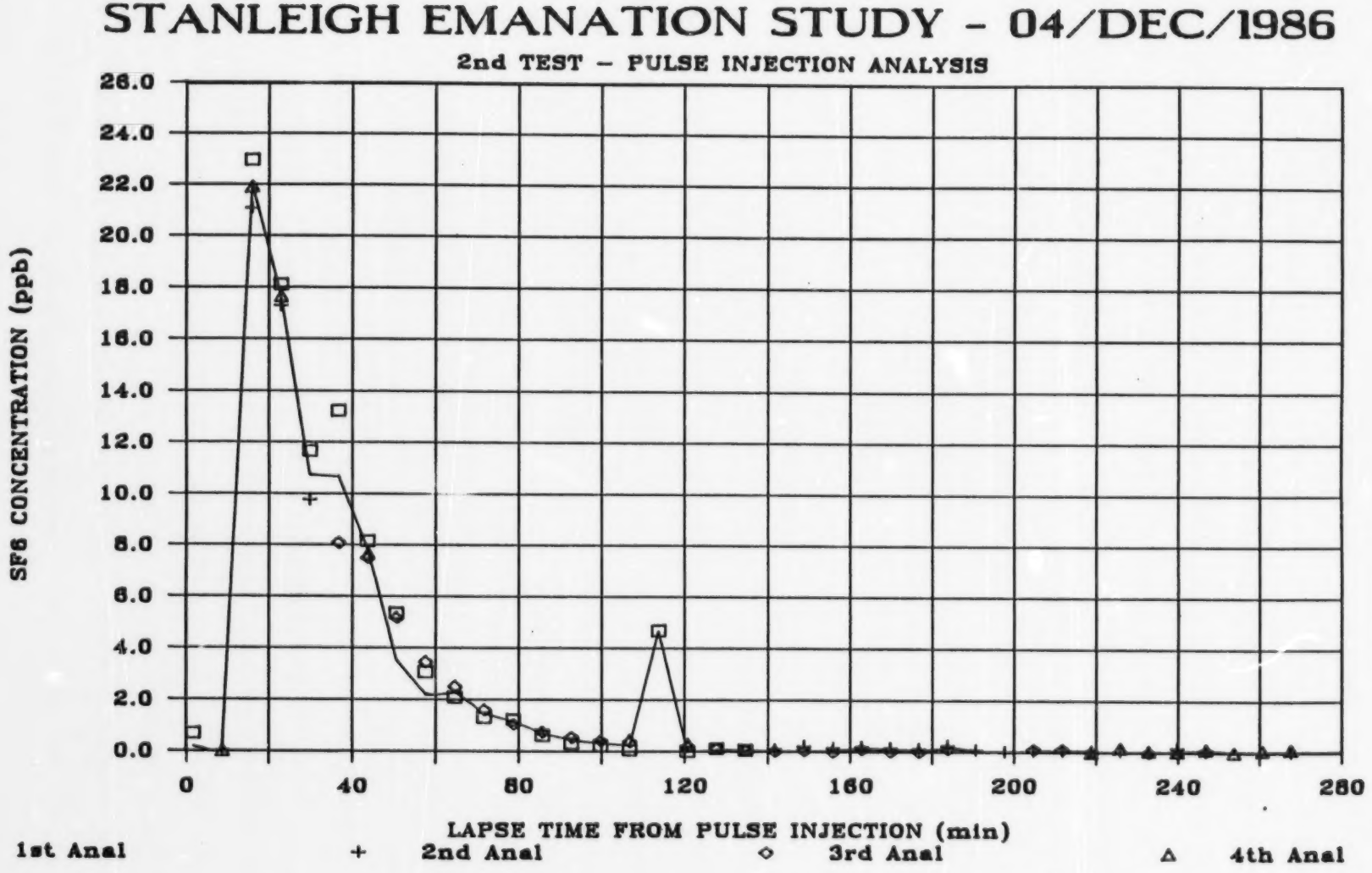

Fig. 4 - Basic analysis of pulse SF_6 injection at sample station #1.

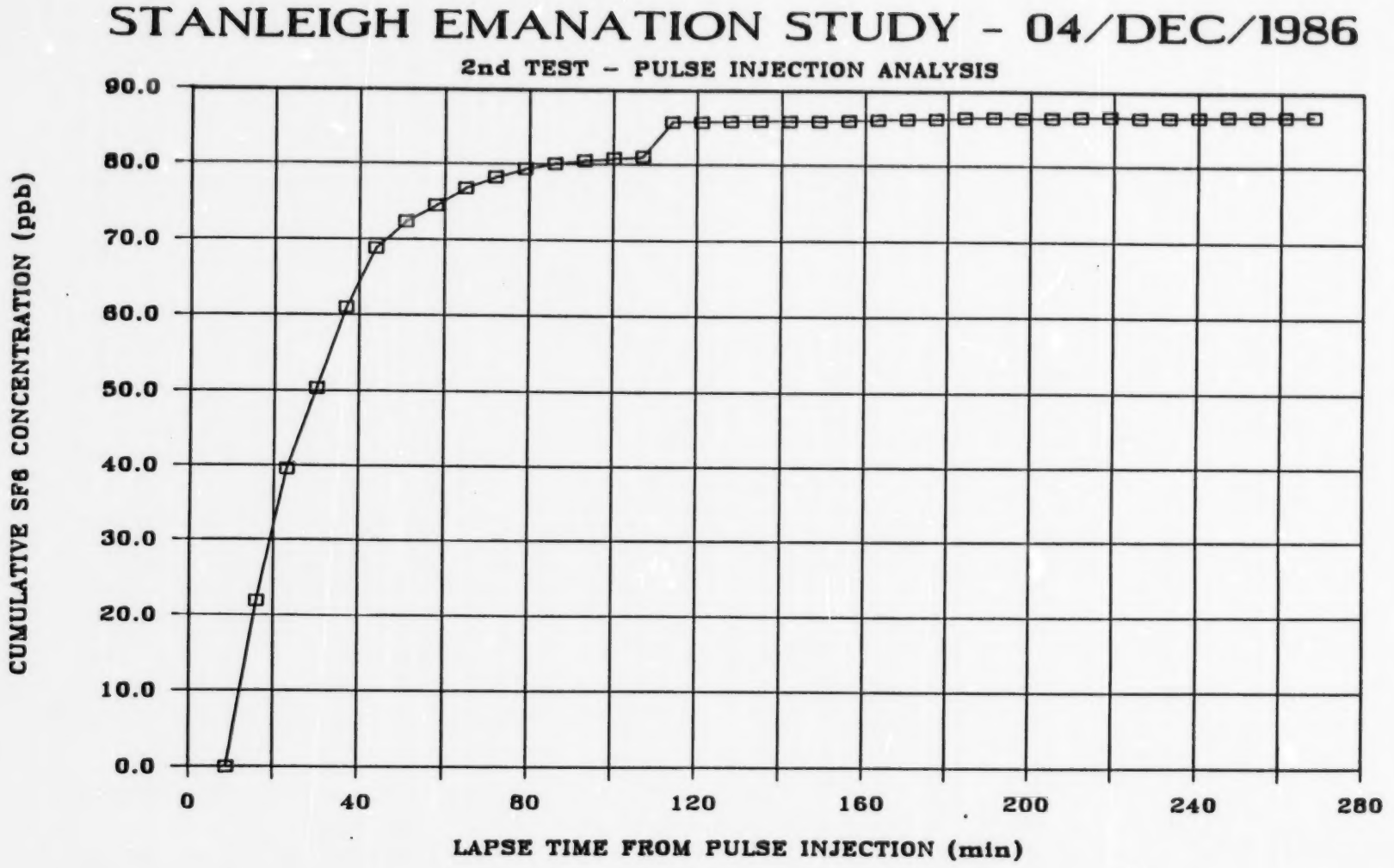

Fig. 5 - Cumulative SF_6 concentration from a pulse injection at station #1 (including recycled gas).

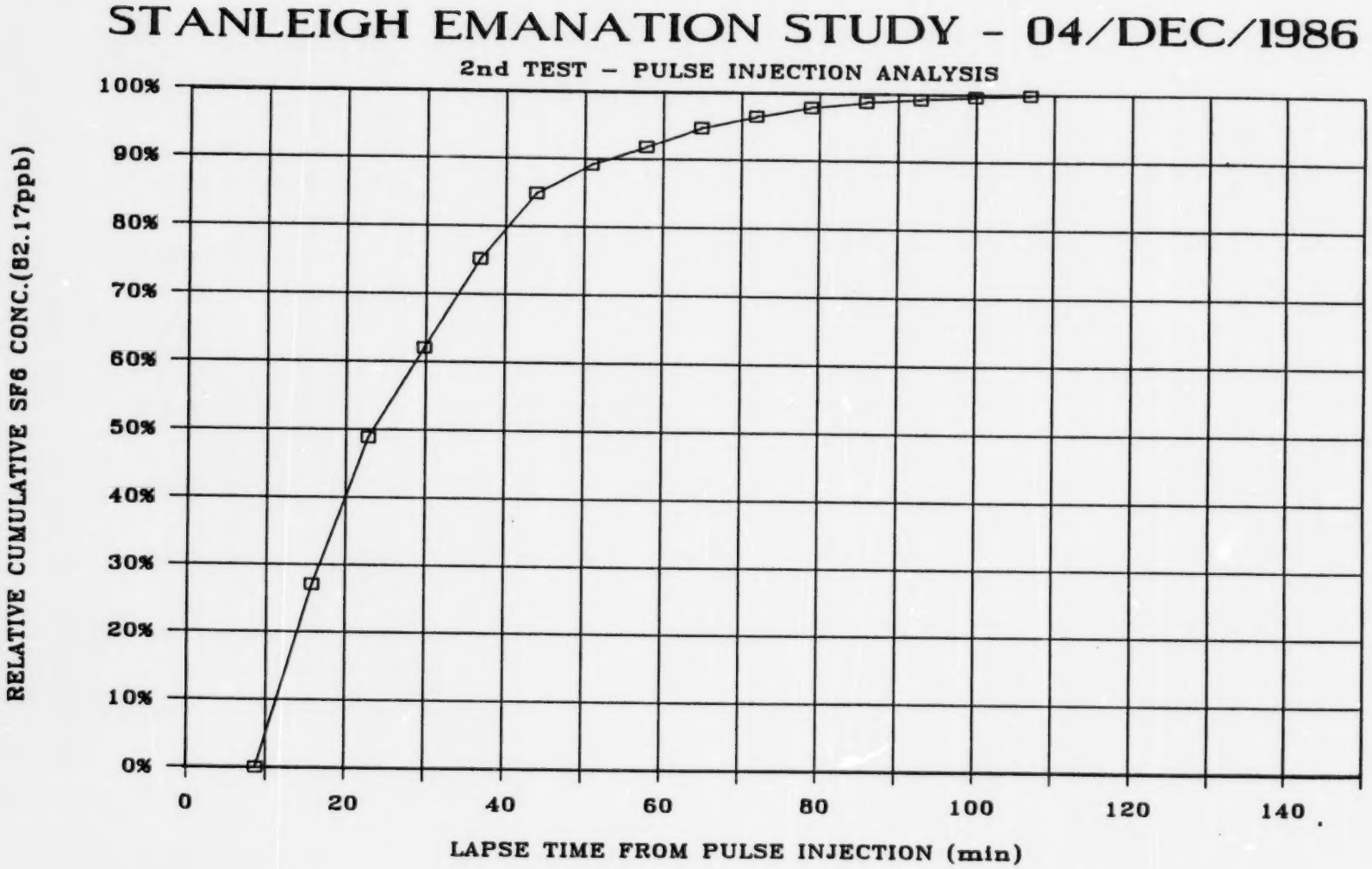

Fig. 6 - Cumulative SF_6 percentage curve for primary gas peak from the pulse injection (excluding recycled gas).

minutes. The value from this pulse injection analysis would be more typical as there was no restriction in the exhaust shaft during the injection. Again the total clearance time including the recycle peak is approximately 300 minutes.

ANEMOMETRY RESULTS

During pulse injection and its sampling the airflows in the area were measured by conventional anemometry. The results from this survey are shown in a flow chart representation of the area in Figure 7. The anemometry survey highlighted the source of the recycled air and two other minor fresh air inputs to the ventilation of the lower reef. Figure 7 shows the flow in both metric and imperial units. Also given are the calculated percentages of the original concentration of SF_6 for:

i) the continuous injection on reaching steady state;

ii) the major pulse of the pulse injection; and

iii) the recycled part of the pulse injection.

The first major dilution of the airstream and SF_6 is the additional 47 m^3/s from the haulage level which, however, contains 14 m^3/s recycled air. Depending on the type of injection used this recycled air will have differing effects on the resultant concentrations downstream.

For continuous injection the effect of this recycling will affect the ultimate steady state. Initially the injection will be diluted by clean air until air containing SF_6 has completed the recycle loop. According to the sample analysis the cycle time is approximately 110 minutes. At this time the injection will start to be diluted by air already containing SF_6 and the resulting combined concentration will be higher. This results in the dilution air having a higher concentration SF_6 in the second complete cycle of the loop. If the initial concentration was 100% the dilution and mixed streams

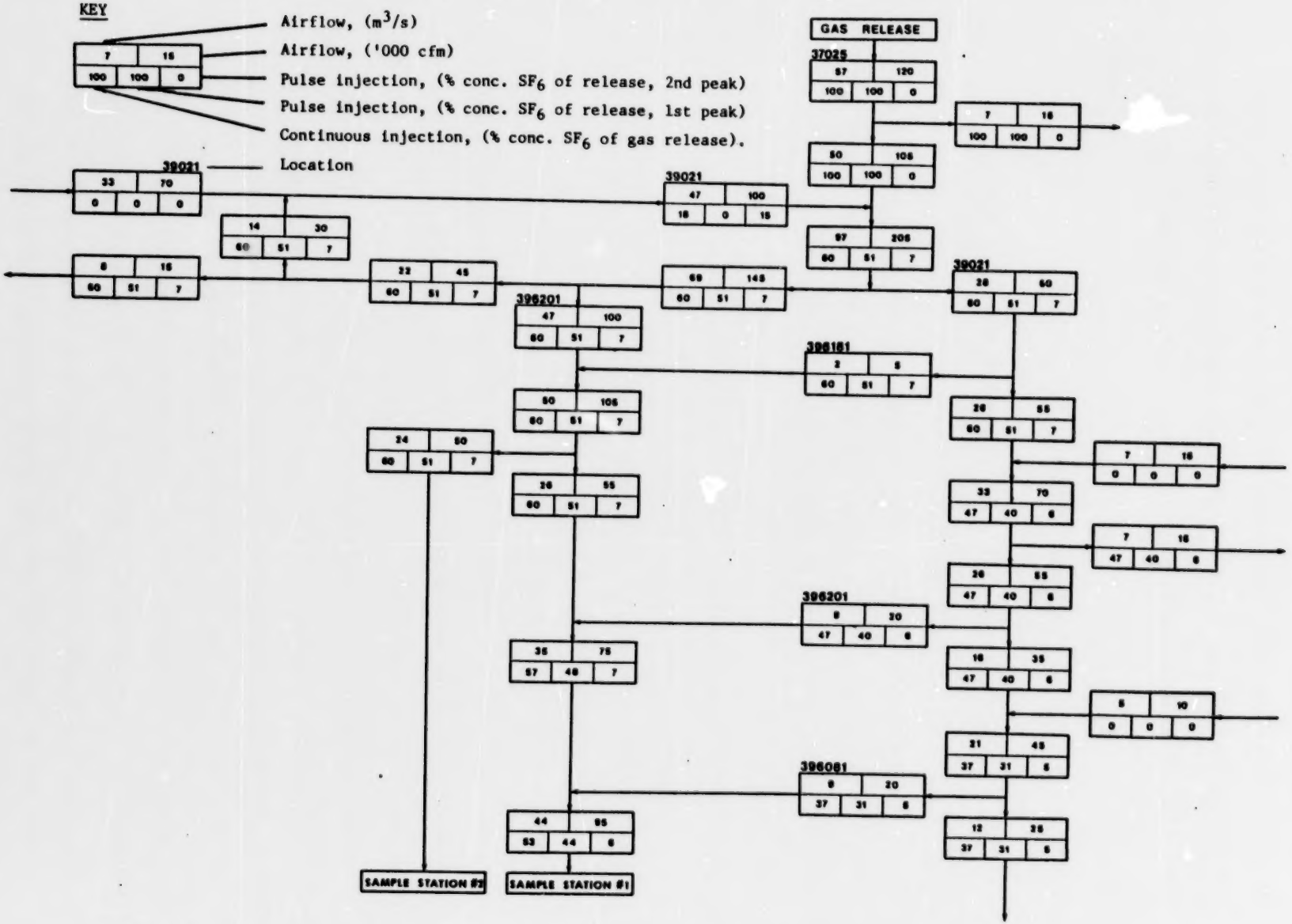

Fig. 7 - Airflow distribution in the test location from anemometry, and tracer gas dilution for both types of SF_6 injection.

would have the following values:

Cycle #	Dilution Stream	Combined Stream	% Steady State
0	0.0%	51.2%	85.3
1	15.4%	58.7%	97.8
2	17.6%	59.8%	99.7
3	17.9%	60.0%	99.9
4	18.0%	60.0%	100.0
5	18.0%		

The air in this recycle system quickly reaches steady state. After two completed loops (approximately 220 minutes) it has reached 98% of its final value.

The air input from the haulage level has a completely different result on the pulse injection. On primary dilution the recycled air will not contain any SF_6 and will result in a 51.2% concentration in the combined stream as for the first cycle above. By the time this air has completed the recycle loop it has been diluted down to 15.4%. At the second dilution, 110 minutes later, only the recycled air would contain any SF_6, the intake would be clean, and the resultant combined stream would be 7% of the original.

The dilution from the haulage level takes place just prior to the air leaving the main reef. The air entering the lower reef therefore has the three major concentrations of SF_6. Expressed as percentages of the original concentration at the release point, these are, 60% under steady state, and 51% and 7% for the primary and secondary peaks of the pulse injection.

Of the two airstream splits in the lower reef, only one was affected by any further introduction of fresh air. The airflow to Sampling Station #2 proved to be unaffected and stayed at 60, 51 and 7% of the original concentration. The airstream to Sample Station #1 was further diluted by two small inputs, 7 and 5 m^3/s, but these only partially affect the survey

station. The resultant concentrations at Station #1 are 53, 44 and 6% of the original.

Similar calculations would show that the percentage of the original air or SF_6 at the release point to reach the stations under the same three conditions would be:

Station #1: 41, 35 and 5%

Station #2: 25, 21 and 3%.

The contribution of the second recycle loop to both the air and SF_6 would be less than 1%.

According to the anemometry data, 14.6% of the air, 14 m^3s in 97 m^3/s (30 000 in 205 000 cfm), is being recycled in the system. Under the two injections different values are obtained for the amount of air being recycled. For the continuous injection 31% recycle peaks were encountered including the decay from the previous peak or steady state, but after correction these reduced to only 25%. For the pulse injection the second peak was 9% of the first and no correction was necessary.

Even though the flows measured during the continuous injection were lower, their relative distribution should be the same; thus the 53% and 60% of original release concentration reaching the sampling stations should apply. With this assumption, the concentrations measured at the two stations would have resulted from an initial flow at the SF_6 release point of 38 to 39 m^3/s (~80 000 cfm). The anemometry value at the gas release location was 52 m^3/s, which is 33% greater.

For the fully diluted flows measured at the sample stations an additional 27 m^3/s of fresh air (excluding recycled air) has entered from the haulage level, and an additional 6 m^3/s has entered enroute to Sample Station #1.

For the pulse injection, the indicated concentration at the sampling

station should have been 44% of the original at the gas release point. Hence, of the 95.5 m^3/s measured, 42 m^3/s (90 000 cfm) was the original flow. Again the anemometry result was 33% higher at 57 m^3/s.

In this instance the fully diluted flow measured at Station #1 had been further diluted by 53 m^3/s additional airflow from the haulage level, recycled air and the two small inputs.

According to the anemometry survey analysis only 35% of the airflow and SF_6 at the release point reaches Station #1. For the SF_6 analysis that is 33 m^3/s as compared with the anemometry value of 44 m^3/s which is 33% greater.

SUMMARY OF RADIATION DATA FOR THE WORKED-OUT AREA

Figure 8 shows radon gas concentrations [^{222}Rn] and radon progeny Working Level, WL(Rn), taken for the day of the tracer gas pulse injection (square brackets are used to denote activity concentration). Thoron progeny Working Level, WL(Tn), measurements were also taken during the same period. The data were collected in the vicinity of survey station #1, downstream of stope #396081 in sill drivage #39022.

A summary of some of the derived data ratios of practical interest are given below:

a) $(WL(Rn)/[^{222}Rn]) \times 10^2 \sim 0.5$, where [$^{222}Rn$] is given in $pCiL^{-1}$;

b) $WL(Tn)/WL(Rn) \sim 0.8 - 1.1$;

c) $[^{214}Pb]/[^{218}Po] \sim 0.6$ and $[^{214}Bi]/[^{218}Po] \sim 0.4$

where [^{214}Pb] is Radium B, [^{218}Po] is Radium A, and [^{214}Bi] is Radium C.

The above ratios are related to the ventilation characteristics of the area (1). The values obtained indicated that the section of the mine selected for the study was fairly well ventilated. A detailed analysis of radioactivity concentration levels as related to underground airflow conditions, and a comparison of theoretical and experimental data, is given

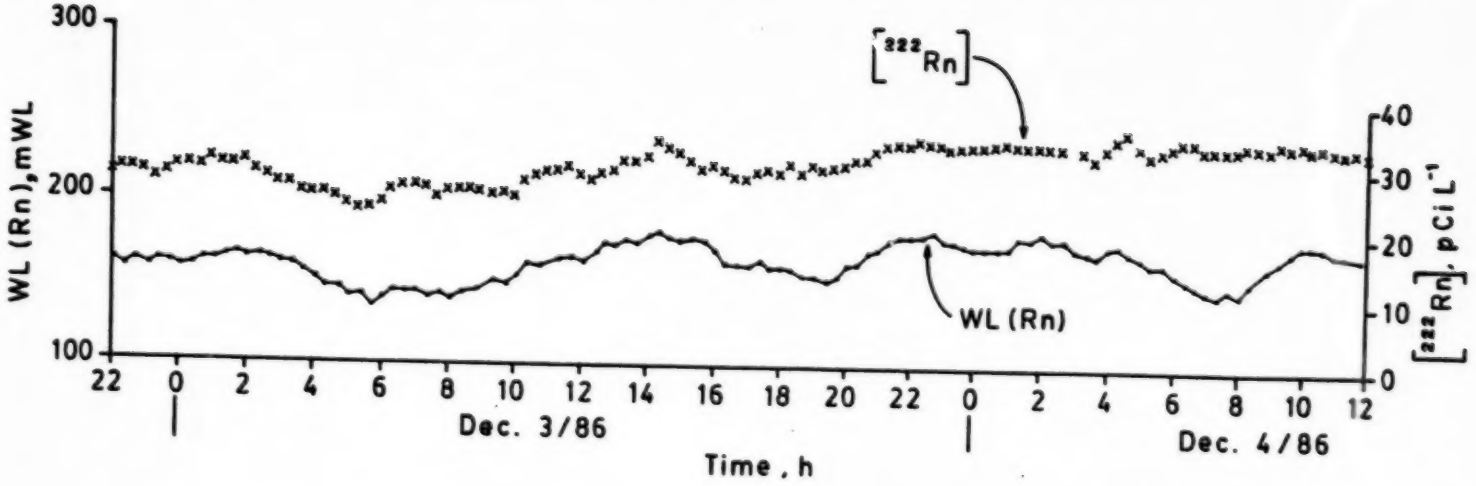

Fig 8 - Radon gas concentration and radon progeny Working Level, including the day of the pulse injection.

elsewhere (1).

DISCUSSION AND CONCLUSIONS

The two injections provided some very interesting results, the least of which was a 33% discrepancy between anemometry and tracer gas values for the dilution airflows.

Both the pulse and continuous injections also indicated that air was being recycled in the area under investigation which complicated the analysis of the results. The presence of a recycling loop would make any further attempts to quantify individual airflows even at the stations extremely tenuous.

The analysis was also complicated by three fresh air inputs to the ventilation of the area. These include the intake from the haulage level and two others that were not highlighted prior to the study. The latter two, however, did not affect the sampling at Station #2, but unfortunately the pulse injection was only monitored at Station #1.

The fresh air input from the haulage level was further complicated in the analysis as it also contained the recycled air.

As well as air inputs, there was also air lost via four output airpaths but these outputs had minimal effect on the continuous injection analysis. If enough manpower and sampling bags were available to measure these inputs and outputs, then the complete exhaust distribution could have been obtained for the pulse injection.

The pulse and continuous injection analyses provided the following information:

i) During the continuous injection the initial flow through the main reef was 39 m^3/s;

ii) item i) combined with 27 m^3/s of fresh air entering from a haulage level

prior to entering the lower reef (this air had already been mixed with the recycled air from the lower level);

iii) in the lower reef an additional 6 m^3/s had combined with the flow to one of the sample stations;

iv) the flows during the continuous injection were lower than usual due to a constriction in the exhaust shaft;

v) During the pulse injection the initial flow through the main reef was 42 m^3/s;

vi) item v) combined with 53 m^3/s from the haulage level, recycled air, and two other minor fresh air inputs;

vii) the flow at Sample Station #1 was 33 m^3/s;

viii) both the pulse and continuous injection analyses showed that air was being partially recycled and that the air took 110 minutes to complete a cycle;

ix) for both the pulse and continuous injection analyses the overall clearance time of the area was up to 300 minutes but this included the recycled air. Under normal flow conditions with no recycling the pulse injection indicated a 95% clearance within 60 minutes and a total clearance time of 110 minutes;

x) the average residence time of the system was higher during the continuous injection because of lower flows in the area. To Station #1 the time was 52 minutes and to Station #2, 43 minutes. For the pulse injection the average residence time was 24 minutes.

Various improvements could be made for future airflow measurements for emanation studies in this area:

1) If possible the mine should prevent the recycling of air between the two reefs.

2) Preferably the majority of all future sampling should be done at Station

#2 as these samples are subject to less dilution than those at Station #1.

3) Sampling should also be performed in the upper reef prior to the dilution from the haulage level.

4) Sampling should also be performed across all other dilution points and at various points along the flow path.

5) If feasible, gas releases should be performed from other locations along the flow path and preferably two or more should be performed immediately after each other on the same day. This is only possible with the present equipment, and using a single tracer gas, if the recycle loop is removed.

6) This investigation would be greatly improved when the chromatograph is modified for use underground.

Ratios relating radon and radon progeny and thoron progeny to radon progeny show the area investigated to be fairly well ventilated.

ACKNOWLEDGEMENTS

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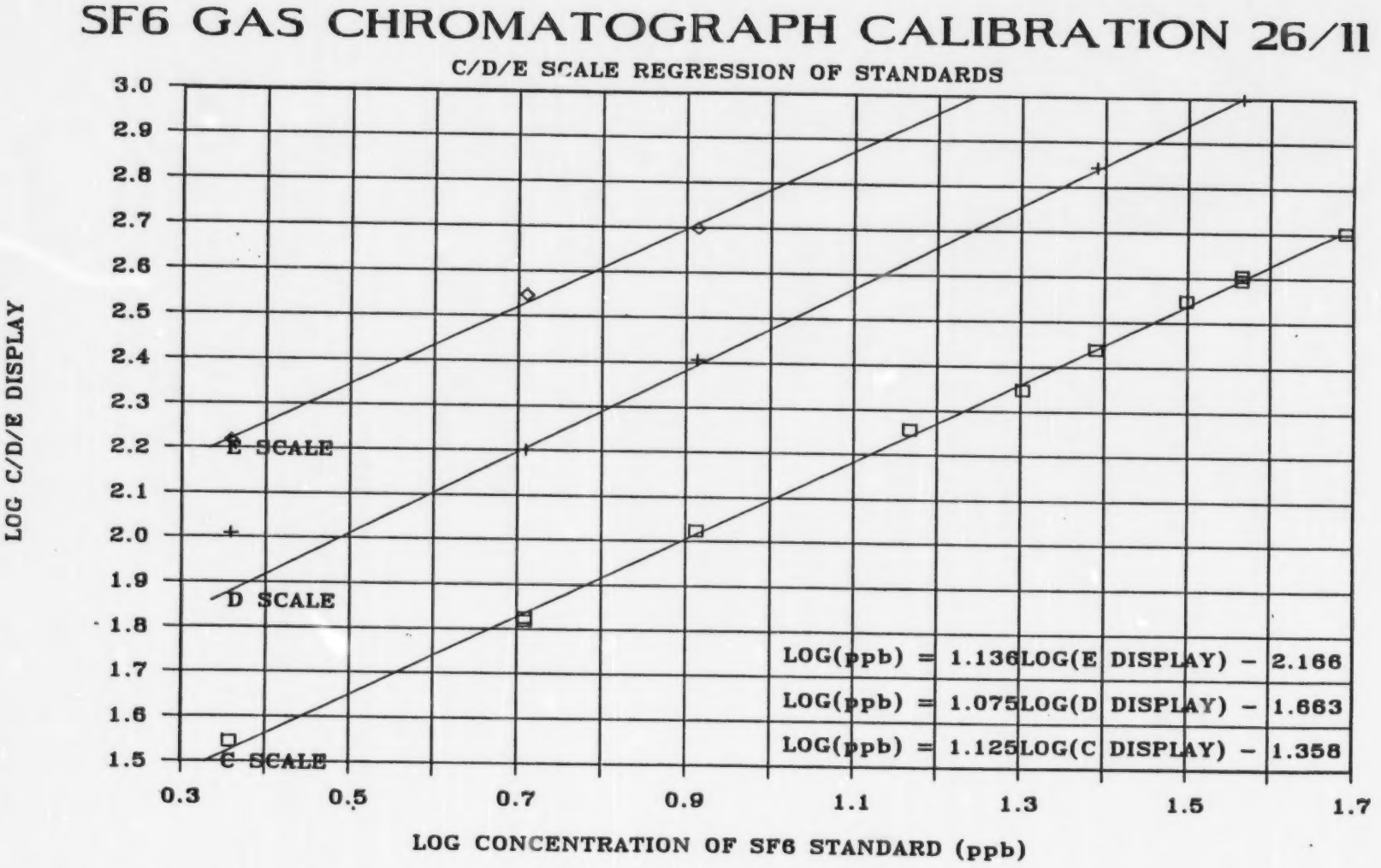

Fig. A-1 - Calibration curves of gas chromatograph for Sulphur Hexafluoride (SF_6) for the continuous injection.

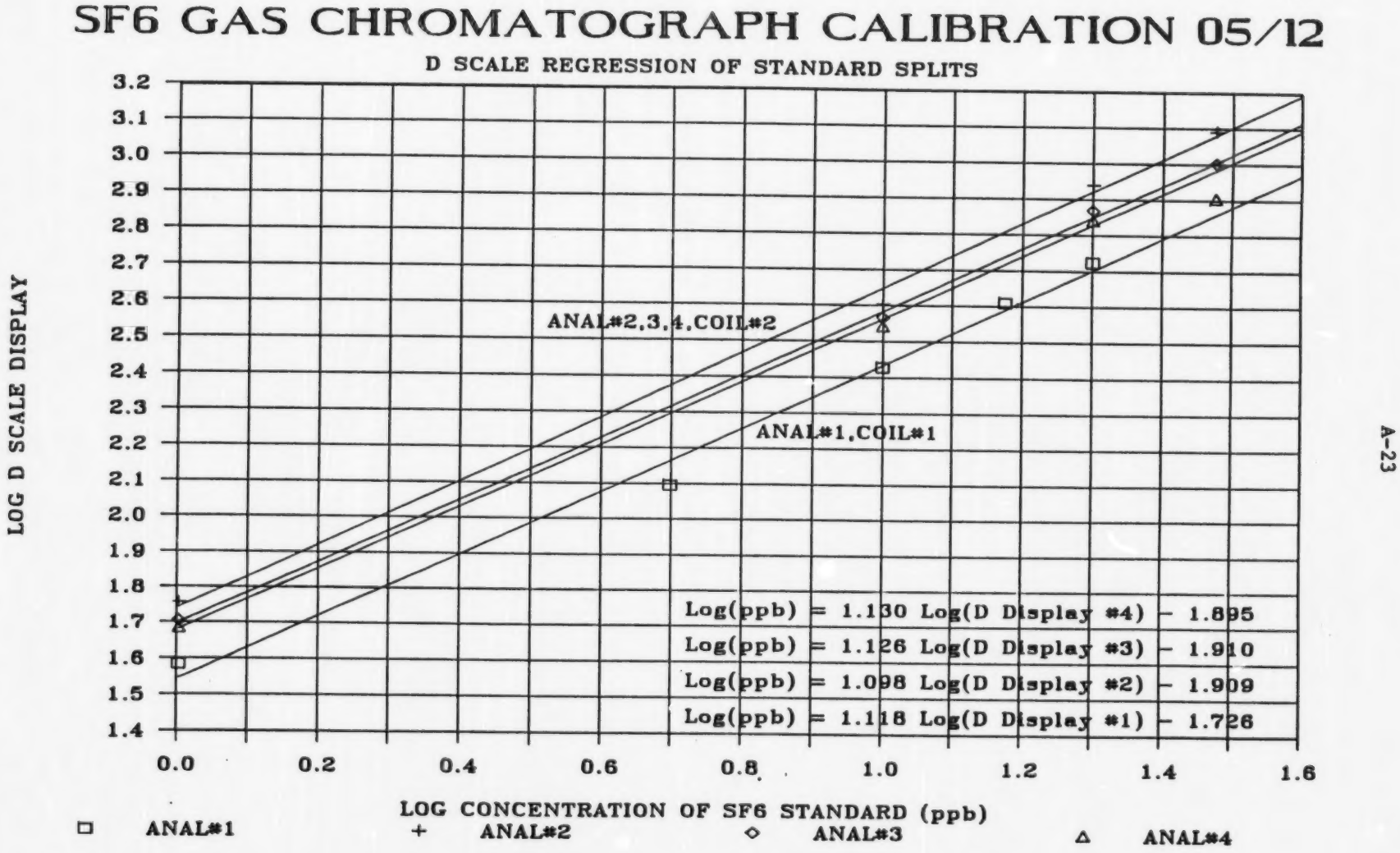

Fig. A-2 - Calibration curves of gas chromatograph for SF_6 for the pulse injection.